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Next Generation Networks

Wireless local area networks: IEEE 802.11

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Wireless local area networks: motivation

- Simplicity
  - ✓ Easy to install, reasonably simple to manage
  - ✓ Planning is often ad hoc, does not require new cabling
- Support for nomadic users
  - ✓ Hot spots, office and public buildings
- Robustness to disasters
  - ✓ Weak dependence on infrastructure
- Spontaneous deployment
  - ✓ Community networks
  - ✓ Participants form a network on the fly
- Cost

Limitations (1)

- Quality of service
  - ✓ Typically, throughput is lower than wireline counterparts
  - ✓ Limited support for service differentiation or guarantees

- Regulatory issues
  - ✓ Limitations on maximum transmit power
  - ✓ Often operate in ISM bands (along w/ other types of devices)

Industrial, Scientific and Medical

Limitations (2)

- Coexistence
  - ✓ Multiple standards (802.11a, 802.11b/g, Bluetooth, etc.)
  - ✓ Overlapping frequency bands (ISM band)

- Security
  - ✓ Easy to eavesdrop

Goals (1)

- Global operation
  - ✓ Coordination of international spectrum regulation
  - ✓ License-free operation
- Low power
  - ✓ Limited battery life without recharging, then one tries to consume little power
  - ✓ Safety considerations: low power emissions (e.g., not to disturb communications ongoing in ISM bands)
- Robustness
  - ✓ Need to overcome impairments of wireless medium
  - ✓ Support for nomadicity (ideally, mobility)

Goals (2)

- Interoperability
  - ✓ WLAN/wireline networks; WLAN/WWAN (e.g., 802.11/3G-4G-5G); WLAN/WPAN (e.g., 802.11 /Bluetooth)
- Security
  - ✓ e.g., privacy, robustness to denial of service
- Application support
  - ✓ When relevant, should support context and location aware computing
  - ✓ When not relevant, should be transparent to the application

LOS = Line Of Sight

Infrared vs. radio

~ $10^{-4} – 10^{-7}$m, 10^{12} - 10^{14} Hz

- Infrared
  - ✓ Short-range point-to-point data transfer
  - ✓ Can use diffused reflected light, but generally requires LOS for good data rates
  - ✓ Sender: light-emitting diodes or laser diodes
  - ✓ Receiver: photodiodes
- Radio
  - ✓ Most wireless networks use radio frequencies

~ $10^{4} – 10^{-1}$ m, 10^{4} - 10^{9}Hz

Infrared / radio comparison

Infrared	*Radio*
(+) Inexpensive senders and receivers (+) No license required (+) No interference with electrical devices	(+) Long term experience (+) Radio waves can travel long distances and penetrate walls, vegetation (+) Much higher data rates are possible than using infra-red
(-) Comparatively low data rates (-) Easily shielded by obstacles such as walls, vegetation	(-) Interference (-) Limited to certain frequency bands

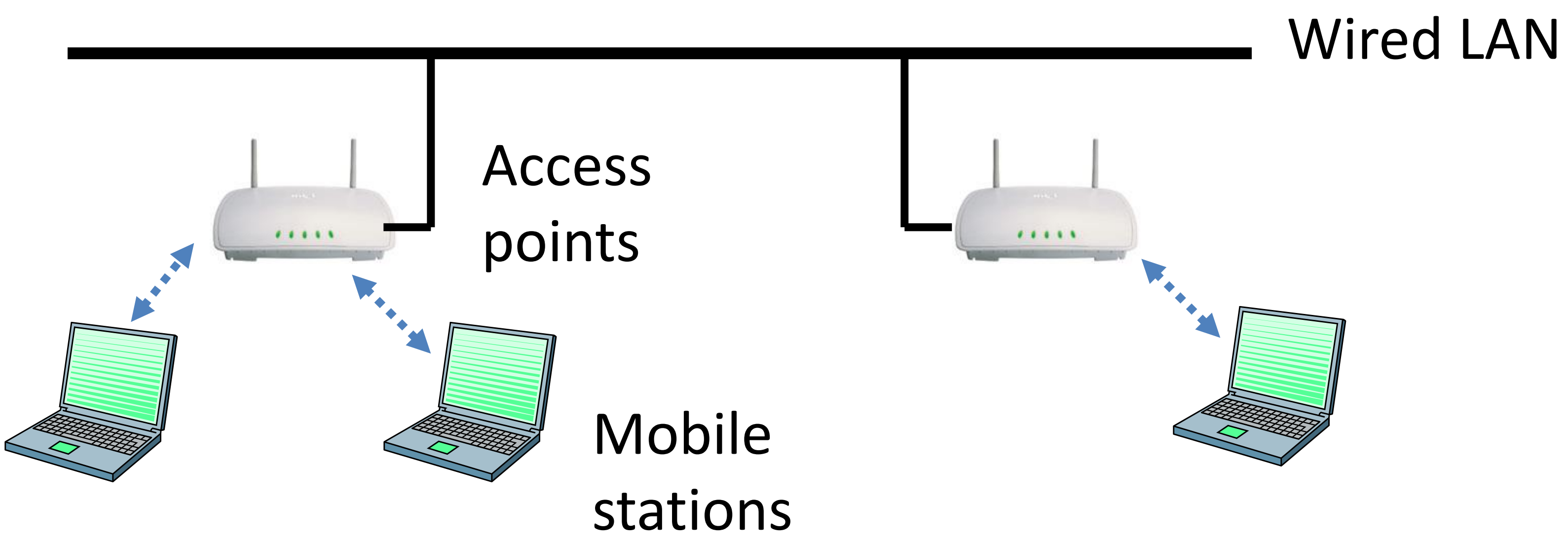
Infrastructure-based vs. ad-hoc

- Infrastructure-based
  - ✓ Access point is responsible for forwarding messages, limited control and management functions
  - ✓ Applications: office-wide WLANs, hotspots

- Ad hoc
  - ✓ Stations communicate directly with one another, may perform routing functions
  - ✓ Applications: military (combat environments), impromptu meetings, sensor networks, vehicular networks

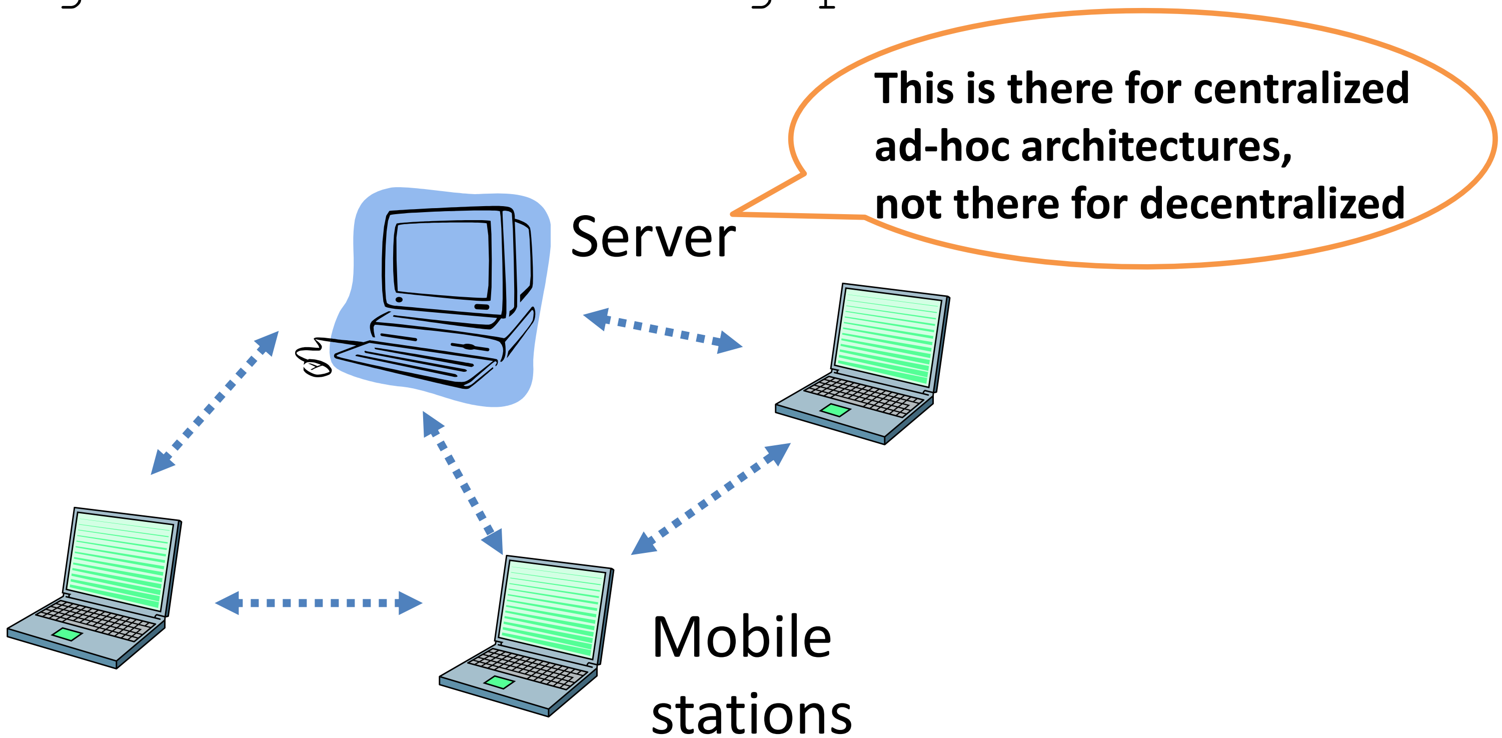
Infrastructure mode

- Access point acts as a bridge to other wireline and wireless networks



Ad-hoc mode

- No central entity with management and control functions
- For multi-hop communication, stations must be running an ad hoc routing protocol



Wi-Fi

- Wireless Fidelity
- The Wi-Fi Alliance certifies interoperability of 802.11-based products
  - Non-profit organization founded in 1999
  - Many member companies from several countries

IEEE 802.11b characteristics

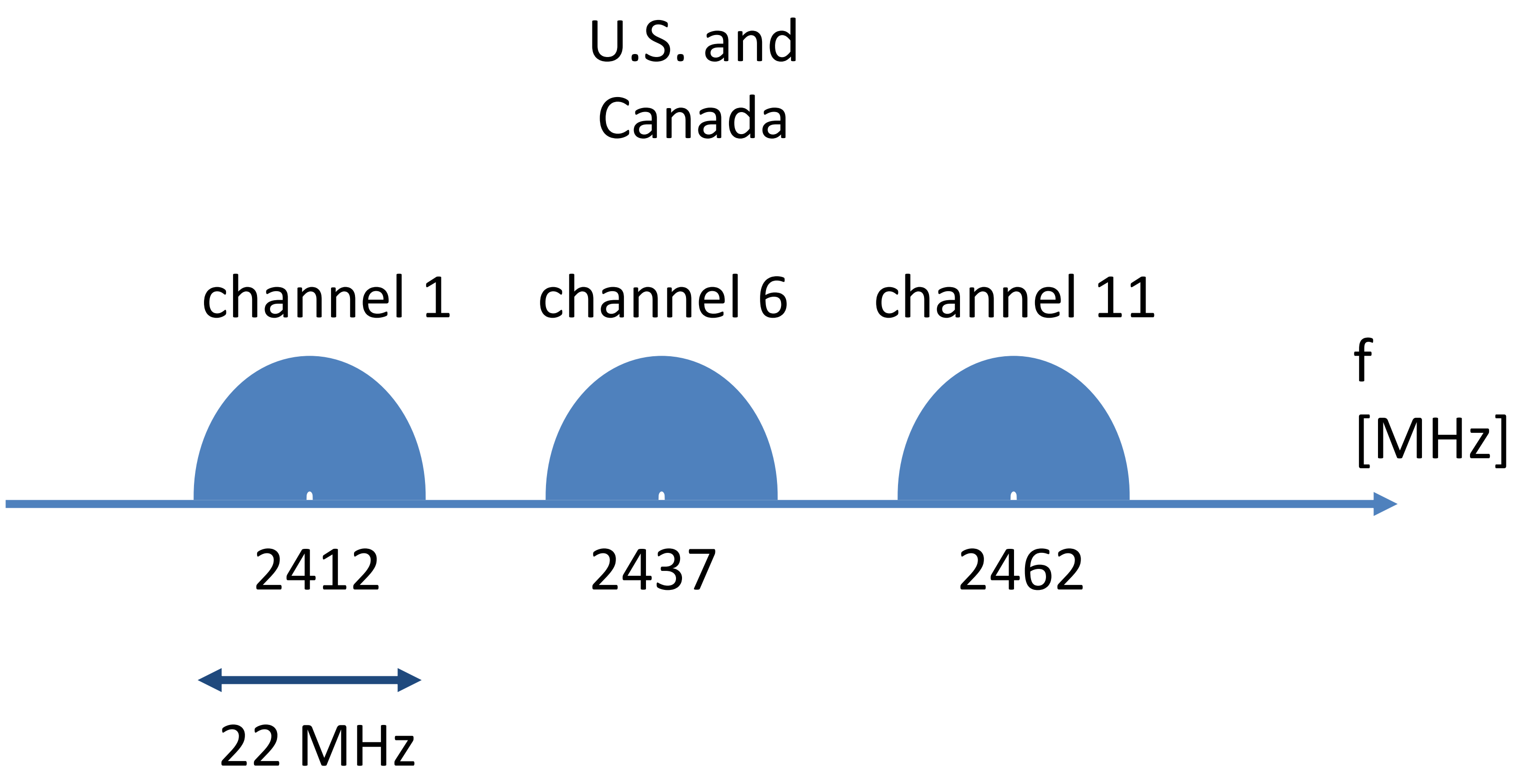
- Higher-speed physical layer extension of 802.11 in the 2.4 GHz band
  - ✓ Same MAC functions
- Offers data rates of 11, 5.5, 2 and 1 Mbps
  - ✓ In practice, maximum achievable user data rate around 6-7 Mbps
- DSSS
- 1 and 2 Mbps use DBPSK and DQPSK, respectively (as in 802.11)

IEEE 802.11b center frequencies

Channel	Freq. (MHz)	US / Can	Eur.	Japan
1	2412	●	●	●
2	2417	●	●	●
3	2422	●	●	●
4	2427	●	●	●
5	2432	●	●	●
6	2437	●	●	●
7	2442	●	●	●

Channel	Freq. (MHz)	US / Can	Eur.	Japan
8	2447	●	●	●
9	2452	●	●	●
10	2457	●	●	●
11	2462	●	●	●
12	2467		●	●
13	2472		●	●
14	2484			●

IEEE 802.11b channel layout



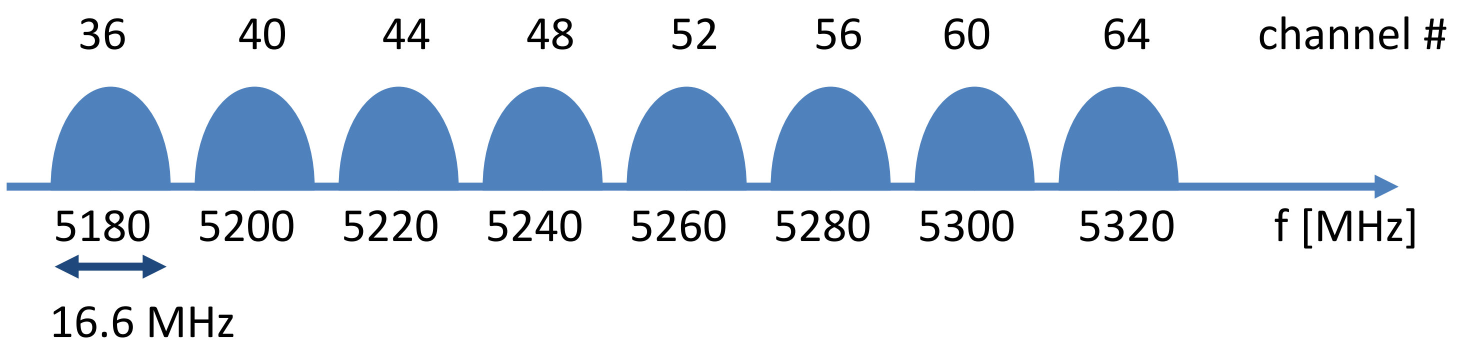
IEEE 802.11a characteristics

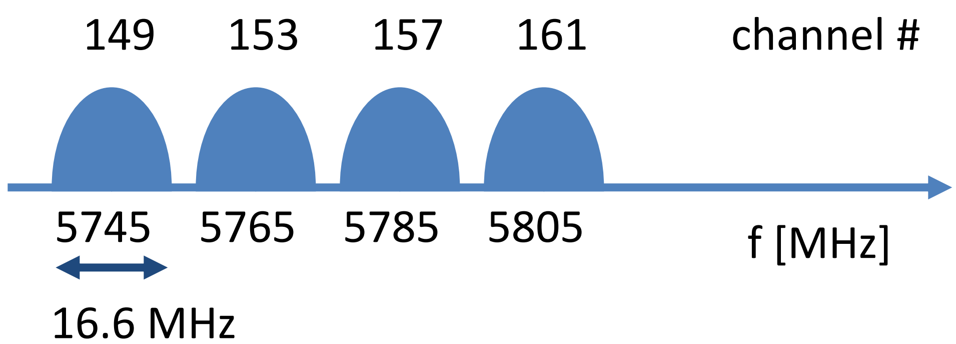
- Products available in the market since 2001
- Operates in the 5 GHz band
  - ✓ Not directly compatible with 802.11b or 802.11g (different bands)
  - ✓ Due to the higher frequency, range is shorter than 802.11b or 802.11g
- 12 non-overlapping channels
- Uses Orthogonal Frequency Division Multiplexing (OFDM) to achieve up to 54 Mbps

OFDM

- Technique that distributes the data over several carriers spaced apart at precise frequencies
- Also used in ADSL and digital TV (in Europe)
- 802.11a uses 52 subcarriers equally spaced around a center frequency
  - ✓ Four of these subcarriers are used for pilot signals (signal detection)

IEEE 802.11a channel layout





Center frequency =
5000 + 5 x channel #

IEEE 802.11g

- Ratified in 2003, tries to combine best features of 802.11a and 802.11b
  - ✓ Data rates of 20+ Mbps (up to 54 Mbps)
  - ✓ Operates in 2.4 GHz frequency band
- OFDM, forward error correction
- Interoperable with 802.11b

Summary

Standard	Spectrum	Maximum Physical Rate	Maximum Layer 3 data rate (typical)	Transmission
802.11	2.4 GHz	2 Mbps	1.2 Mbps	FHSS, DSSS or IR
802.11a	5.0 GHz	54 Mbps	32 Mbps	OFDM
802.11b	2.4 GHz	11 Mbps	6-7 Mbps	DSSS
802.11g	2.4 GHz	54 Mbps	32 Mbps	OFDM

Pros and cons: IEEE 802.11a

	Advantages	Disadvantages
802.11a	• Fastest maximum speed (among versions discussed so far) • Supports more simultaneous users • Less interference from other devices	• Highest cost • Shortest range signal • More easily obstructed • Not compatible with 802.11b/g

Pros and cons: IEEE 802.11b

	Advantages	Disadvantages
802.11b	• Lowest cost (most widely deployed) • Longest range • Not easily obstructed	• Slowest data rates • Other appliances may interfere in same frequency band

Pros and cons: IEEE 802.11g

	Advantages	Disadvantages
802.11g	• Longest range • Higher data rates than 802.11b • Supports more simultaneous users • Not easily obstructed	• More costly than 802.11b • Other appliances may interfere in same frequency band

IEEE 802.11n

- Higher data rate through the use of Multiple Input Multiple Output (MIMO) techniques
  - ✓ Late 2009
  - ✓ Products based on draft specifications available much earlier
- Operating frequency: 2.4 GHz and/or 5 GHz
- Physical rate: up to 600 Mbps

IEEE 802.11ad (WiGig)

- Early 2010’s
- Data throughput speeds of up to 7 Gbps
- 60 GHz ISM band
  - ✓ Large bandwidth
  - ✓ Reduced interference
- Range ~ few metres
  - ✓ Used to transfer over very short range (across a room) high volumes of data (e.g., HD video)

IEEE 802.11ax (WiFi 6)

- Official IEEE specification in February 2021

- Designed specifically for high-density public environments, like trains, stadiums and airports

- Also be beneficial in Internet of Things (IoT) deployments

- Designed for cellular data offloading

https://www.networkworld.com/article/3258807/what-is-80211ax-wi-fi-6-and-what-will-it-mean-for-80211ac.html

IEEE 802.11ax (WiFi 6)

- Can deliver a total theoretical bandwidth of 14Gbps

- Maintains backward compatibility with 802.11n

- Piggybacks on Multi-User Multi-Input Multi-Output (MU-MIMO) with Orthogonal Frequency Division Multiple Access (OFDMA)

- Operates in both the 2.4 GHz and 5 GHz ranges, thus creating more available channels

https://www.networkworld.com/article/3258807/what-is-80211ax-wi-fi-6-and-what-will-it-mean-for-80211ac.html

For which of the following scenarios an ad-hoc architecture is least indicated?

- ❑ Disaster aftermath
- ❑ Airport hotspot
- ❑ Vehicular networks

For which of the following scenarios ad-hoc architecture is least indicated?

- ❑ Disaster aftermath
- ✓ Airport hotspot
- ❑ Vehicular networks

Airport hotspot can easily rely on the support of an infrastructure, being the scenario not so complicated to deal with as compared to the other two, e.g., there is the possibility to deploy cables.

In case we want to improve the spectral efficiency of a communication link, we should

(i) Increase the bandwidth, so we can transmit at a higher data rate.
(ii) Increase the number of antennas to perform a more complex spatial multiplexing transmission, so we can transmit more spatial streams simultaneously.
(iii) Use a channel coding scheme providing high redundancy, so we can correct more transmission errors.

(ii) <u>Increase the number of antennas to perform a more complex spatial multiplexing transmission, so we can transmit more spatial streams simultaneously.</u>

➔spatial multiplexing increase the spectral efficiency (no increase in bandwidth as in (i), and no decrease in data rate as in (iii)).

In a machine type communication scenario, where many different transmitters are deployed in proximity of each other, and assuming OFDMA is adopted, what is the best choice as frequency reuse? (motivate your answer)

(i) One.
(ii) Four.
(iii) The choice of frequency reuse is irrelevant in this case.

(ii) <u> Four.</u>

➔ increasing the frequency reuse enables a better protection against interference, as compared to sharing all the bandwidth between all the transmitters (reuse one).